

NUCLEAR WEAPONS STOCKPILE STEWARDSHIP

Lawrence Livermore National Laboratory was established in 1952 to help ensure national security through the design, development, and stewardship of nuclear weapons. National security continues to be the Laboratory's defining responsibility. Livermore is one of the three national laboratories that support the National Nuclear Security Administration (NNSA) within the Department of Energy (DOE).

Livermore plays a prominent role in NNSA's Stockpile Stewardship Program for maintaining the safety, security, and reliability of the nation's nuclear weapons and in NNSA's vision for the future, Complex 2030. The Stockpile Stewardship Program integrates the activities of the U.S. nuclear weapons complex, which includes Livermore, Los Alamos, and Sandia national laboratories as well as four production sites and the Nevada Test Site. Successes to date in stockpile stewardship make possible the Complex 2030 vision of transforming the nation's nuclear weapons enterprise to be less costly, highly secure, and fully capable of responding to national security needs on a timely basis.

As stockpiled nuclear weapons age, Laboratory scientists and engineers are challenged to ensure their performance, refurbish weapons, and as necessary, supply reliable replacements without conducting nuclear tests. The researchers attend to the immediate needs of the stockpile through assessments and actions based on a combination of laboratory experiments and computer simulations of nuclear weapon performance. In addition, Livermore is acquiring more powerful experimental and computational tools for assessing aging weapon systems and certifying reliable replacement warheads. The replacement warheads are central to NNSA's strategy to make the 21st-century complex more responsive to the need for a smaller stockpile that is even safer, more secure, and easier to maintain.

Complex 2030 Sets a Course for the Future

In April 2006, Tom D'Agostino, NNSA deputy administrator for Defense Programs, presented to Congress NNSA's plan for consolidating the DOE weapons complex. The plan, called Complex 2030, builds on the recommendations of the Secretary of Energy's Advisory Board (SEAB) task force on the nuclear weapons complex infrastructure. The SEAB task force recommended that the Cold War nuclear weapons stockpile be replaced with a sustainable stockpile and that NNSA complement its investments in the nuclear weapons laboratories with investments to consolidate and modernize production.

Complex 2030 supports vital 21st-century national security objectives. The United States needs to ensure the long-term safety, reliability, and security of its nuclear deterrent and reduce the stockpile's size to the lowest number of weapons consistent with national security objectives. The life

of selected aging weapon systems must be extended while the complex is transformed to a more sustainable future stockpile and infrastructure. The Reliable Replacement Warhead (RRW), which is discussed below, is a key concept for achieving a smaller stockpile and more responsive infrastructure.

The Complex 2030 plan retains two independent centers of excellence for nuclear warhead design and development at Livermore and Los Alamos, each supported by Sandia for nonnuclear component design. Working together in an integrated program, the laboratories improve their understanding of nuclear weapons science and technology and use their expertise to assess the performance of aging weapons. They also develop necessary refurbishments to weapons to extend their life and pursue concepts for replacement warheads. During a visit to Livermore in May, D'Agostino stressed the importance of Lawrence Livermore "...as a key component of the future of the nuclear weapons program...and national security as a whole."

Achieving the Complex 2030 vision will require significant change. The plan calls for dismantling retired weapons, consolidating special nuclear materials, eliminating duplicative capabilities, establishing a consolidated plutonium center, and implementing more efficient and uniform business practices. All Category I/II special nuclear materials—plutonium and highly enriched uranium—are to be removed from Livermore by the end of 2014, except for small amounts of plutonium for research and development activities. In 2006, NNSA began the inventory reduction process, with materials shipped to Los Alamos.

NNSA Defense Program activities at Site 300 are to be phased out as alternatives for performing the work become available elsewhere. Hydrodynamic testing is to be consolidated at other sites, with all large-scale hydrotesting eventually conducted at the Nevada Test Site. A plan for Site 300 is to be prepared this year. Livermore's Contained Firing Facility (CFF), which is located at Site 300, conducted eight major (large-scale) hydrodynamic tests and



Tom D'Agostino, NNSA deputy administrator for Defense Programs, visited the Laboratory to discuss Complex 2030.



Inside Site 300's Contained Firing Facility, John Given sets up equipment for a "shot" as part of large-scale hydrodynamics testing. These tests are essential for verifying the safety and reliability of the nuclear stockpile.

21 focused (smaller-scale) experiments in fiscal year 2006 in support of the National Hydrotest Program.

In October 2006, NNSA announced plans to prepare an environmental impact statement for Complex 2030. George Allen, director of the NNSA Office of Transformation, visited Livermore in December to discuss complex transition issues with Laboratory employees, and he had his first tour of Site 300 and CFF. Allen also hosted public meetings in Livermore and Tracy, California, to gather public comments about the Complex 2030 plan.

Design of a Reliable Replacement Warhead

In early 2007, NNSA announced its decision that Livermore and Sandia national laboratories will lead the design of the RRW for the U.S. Navy. NNSA will work with the Navy to develop a detailed RRW project plan and cost estimate for developing and producing the system. A team from

Lawrence Livermore and Sandia/California and another from Los Alamos and Sandia/New Mexico submitted RRW proposals; according to D'Agostino, "Both teams developed brilliant designs." Higher confidence in the ability to certify the Livermore design without underground nuclear testing was the primary reason for its selection.

The RRW approach to achieving a long-term sustainable nuclear stockpile is critical to the success of the Complex 2030 vision. The goal is to replace existing aging warheads with ones manufactured from materials that are more readily available and more environmentally benign than those used in current designs. These modified warheads would be less costly to manufacture and maintain by a smaller, modernized production complex. In addition, the designs will include advanced safety and security technologies, and their reliability would be easier to certify without underground nuclear testing. The goal of the RRW is to maintain the current military capability, not to improve it.

A responsive nuclear infrastructure, together with the RRW Program, make possible significant reductions in the size of the nuclear stockpile.

The Nuclear Weapons Council (NWC), a working group of senior officials from the Department of Defense and NNSA, launched the RRW Feasibility Study in 2005 after authorization by Congress. Lawrence Livermore and Sandia/California competed with Los Alamos and Sandia/New Mexico to develop and submit design data packages for an RRW for the nation's sea-based nuclear deterrent. After submission in March 2006, both designs were subjected to detailed interlaboratory peer review and evaluation by teams from the RRW Project Officers Group and members of the U.S. Strategic Command Advisory Group. In December, the NWC determined that "...the RRW is feasible as a strategy for sustaining the nation's nuclear weapons for the long-term without underground nuclear testing."

In developing its design data package, Laboratory personnel worked closely



Staff of the Defense and Nuclear Technologies Directorate celebrate the success of their RRW design proposal with associate director Bruce Goodwin.

with Sandia/California and the production agencies to meet all RRW goals using an approach that combined innovation with tested features. The effort heavily exercised the design, engineering, experimental, and simulation capabilities of the Laboratory. One of the major hydrodynamic experiments executed at Site 300 in fiscal year 2006 proved the soundness of the RRW design and approach. In addition, Livermore worked on developing plutonium-part manufacturing technologies. Features in the “RRW–California” design proposal reduce the need for surveillance activities and improve manufacturability.

Intensive use of Advanced Simulation and Computing Program computers and simulation codes (see p. 9) was crucial to the RRW design effort. Laboratory scientists ran more than 28,000 simulations to examine tradeoffs between performance and ease of manufacturing and to map out margins and uncertainties for potential failure modes. They needed to ensure that the RRW–California design provided large performance margins for all key potential failure modes in order to increase weapon reliability and provide strong assurance that underground nuclear testing would not be required for design certification. The evaluations of weapon performance are underpinned by a formal methodology called quantification of margins and

uncertainties (QMU), which has been developed by Livermore and Los Alamos. Laboratory scientists continue to refine QMU and apply it to all major weapon development and assessment activities.

Now that a baseline design has been selected, the next step is a study to further define and develop detailed cost estimates for the RRW program. This work will support a future decision to seek congressional authorization and funding in order to proceed into system development and subsequent production.

Annual Assessment of the Stockpile

Livermore is a key participant in formal review processes and assessments of the safety, security, and reliability of weapons in the stockpile. In 2006, the Laboratory met all milestones in support of the eleventh cycle of the Annual Assessment Review. First mandated by the President in 1995 and now required by law, the annual review assesses the current status of the stockpile and gives the President an informed judgment of whether a resumption of underground nuclear

testing is warranted to resolve any issues about the reliability or safety of weapons. The formal process is based on technical evaluations made by the laboratories and on advice from the secretaries of Energy and Defense, the three laboratory directors, and the commander-in-chief of Strategic Command.

Lawrence Livermore and Sandia/California prepare Annual Assessment Reports for each of the nuclear weapons systems for which the two laboratories are jointly responsible: the W62 and W87 intercontinental ballistic missile (ICBM) warheads, the B83 strategic bomb, and the W80 and W84 cruise missile warheads. As input to the reports, Laboratory scientists and engineers collect, review, and integrate all available information about each weapon system, including physics, engineering, chemistry, and materials science data. This work is subjected to rigorous, in-depth intralaboratory review and to expert external review, including formal use of red teams. Weapons experts from Livermore also provide peer review for the Annual Assessment Reports prepared by Los Alamos and Sandia/New Mexico for the weapon systems under their joint responsibility.

Representative Ellen Tauscher (Tenth District, California, center), and General James Cartwright, commander of the U.S. Strategic Command (right), visited the Laboratory in October. They met with Laboratory director George Miller (left) and received briefings on national security progress and science and technology accomplishments.



Near the end of the 2006 process, the directors of Livermore and Los Alamos national laboratories, together with senior managers in their weapons programs, met to jointly review the nuclear weapons stockpile. The meeting was an opportunity to become better informed about each other's weapon systems, discuss issues, and look for additional opportunities for increased collaboration. This was the first year that such a joint session was held. It will become part of the Annual Assessment Review in future years to further strengthen the overall process.

Predictive Simulations Support Stewardship

The Advanced Simulation and Computing (ASC) Purple and Blue Gene/L computers at Livermore, with a combined peak capability of nearly half a petaflop (that is, nearly 500 trillion floating-point operations per second), are making major contributions to stockpile stewardship problems ranging from RRW design to plutonium aging to fundamental weapons physics. Scientists and engineers at all three NNSA laboratories are using these machines to usher in a new era of predictive simulation.

ASC Purple is capable of operating at nearly 100 teraflops. It was delivered from IBM in 2005, tested, and brought into use for classified production runs in April 2006. With over 12,000 next-generation IBM Power5 microprocessors and 2 million gigabytes of storage, Purple is currently ranked the fourth fastest computer in the world by the Top500 organization. Soon after Purple began operating, a joint team of scientists from Livermore and Los Alamos performed a series of weapon simulations at unprecedented spatial resolution using the most advanced ASC simulation software. The results gave dramatic new insights into weapons physics by pointing

to phenomena not seen at lower resolution. The machine runs the most demanding three-dimensional weapons simulation codes with high-fidelity physics models.

BlueGene/L is number one on the Top500 list of the world's fastest supercomputers, clocking an astonishing 280.6 teraflops on the industry standard LINPACK benchmark. With its 65,536 nodes (131,072 processors) and "system-on-a-chip" technology, BlueGene/L is a world apart from other scalable computers not only in terms of performance but also in size, cost, and design. BlueGene/L contributes to stockpile stewardship by performing simulations of materials at atomic and molecular scales and of hydrodynamics phenomena. It has been remarkably successful, efficiently running simulation codes capable of addressing a broader range of weapons issues than originally envisioned.

For the second year in a row, a Livermore-led team won the Gordon

Bell Prize for Peak Performance for a materials-science simulation using BlueGene/L. A second Special Achievement award was granted to a team that included a Livermore scientist. The prizes are awarded to innovators who advance high-performance computing.

The calculations for the first award set a world record for a scientific application by achieving a sustained performance of 207.3 teraflops. Qbox, a first-principles quantum molecular dynamics code designed to predict the properties of materials under extreme conditions, was used to study 1,000 molybdenum atoms under high pressure. Molybdenum, a heavy or high-Z metal, is of particular interest to scientists in the Stockpile Stewardship Program. Until now, such quantum simulations have been restricted to about 50 atoms. Simulations of 1,000 atoms make possible studies of hetero-geneous mixtures of molecules and "extreme chemistry." Classical molecular dynamics calculations are



Mark Seager of the Computation Directorate accepts the certificate for the world's fastest supercomputer, BlueGene/L, during announcement of the new Top500 list in Tampa, Florida.

typically much larger in size; the Laboratory's Gordon Bell prize-winner in 2005 was a 2-million-atom simulation of the resolidification of tantalum.

Assessing the Lifetime of Plutonium Pits

A concerted long-term study by Livermore and Los Alamos researchers showed that the performance of plutonium pits in U.S. nuclear weapons will not sharply decline due to aging effects. Because plutonium is highly radioactive, over time it damages materials in weapons, including the pits themselves. However, the effort concluded that the plutonium pits for most nuclear weapons have minimum lifetimes of at least 85 years. These definitive results met a major Stockpile Stewardship Program milestone, and the answer has important implications in planning for the weapons production complex of the future.

Laboratory researchers executed a broadly based program of experiments, simulations, and analyses of previous

underground nuclear test results to provide the data needed for the pit assessment. Understanding the detailed properties of plutonium metal and alloys and how they age is a major scientific challenge because plutonium is an unusually complex material. Among the sources of data are experiments conducted at the Joint Actinide Shock Physics Experimental Research (JASPER) facility at the Nevada Test Site. JASPER's two-stage gas gun can accelerate a projectile to high speeds and produce an extremely high-pressure shock wave in the targeted material—plutonium—upon impact. Through precise measurements of shock velocity, scientists are improving plutonium equation-of-state models. In fiscal year 2006, eight such experiments were conducted at JASPER, including two experiments with aged plutonium and the first joint experiment with Los Alamos scientists.

In addition, Livermore scientists conduct many types of laboratory experiments, including high-pressure equation-of-state

measurements using a diamond anvil cell, x-ray diffraction studies, and transmission electron microscopy analyses. Data from these experiments are used in computer simulations that model the properties of plutonium and the performance of aged weapons.

Materials under Extreme Conditions

The large variety of simulations and experiments exemplifies the great interest and expertise Laboratory researchers have in materials under extreme conditions of pressure and temperature—for stockpile stewardship, inertial confinement fusion, and many other applications. For example, in the September 17, 2006, edition of *Nature Materials*, Livermore researchers and collaborators at Oxford University presented the results of very-large-scale simulations of the dynamical behavior of metals subjected to a strong shock. Because of the size of their simulations and the inclusion of pre-existing

Shock experiments conducted at the JASPER gas gun contribute to understanding plutonium, an essential material in nuclear weapons. Eight tests were performed at JASPER in fiscal year 2006, including the first joint Livermore–Los Alamos experiment.



defects in the crystal, they were able to reproduce experimentally observed three-dimensional effects in shock-compressed material for the first time. A strong shock creates many line defects (dislocations) in the crystalline structure of metals, and this movement relaxes the strain caused by the shock. Among new insights, researchers found that if the shock is too abrupt, the dislocations form too rapidly and become entangled before they can move far enough to relieve the strain.

Together with a variety of collaborators, Laboratory scientists are developing new experimental techniques to gather better data at the nanometer and sub-nanosecond scales characteristic of the simulations.

One technique, dynamic x-ray diffraction, uses high-intensity lasers to generate both a shock in a solid and a precisely timed flash of x rays to image the lattice in motion. When the x rays interact with the crystal's atoms, they are diffracted in a pattern that characterizes the lattice. By resolving this time-dependent diffracted signal, scientists can develop a fundamental understanding of the kinetics of transformation and lattice relaxation.

Dynamic x-ray diffraction experiments have been performed at the Trident laser at Los Alamos, the Omega laser at the University of Rochester, the Vulcan laser in the United Kingdom, and the high-

energy Janus laser at Livermore. Janus is part of the Laboratory's Jupiter Laser Facility, which includes the Janus, Callisto, Europa, COMET, and Titan lasers and associated target chambers. As reported in *Physical Review Letters* on June 30, 2006, Laboratory scientists used the Europa femtosecond (one millionth of a nanosecond) laser to convert a nanofoil of gold into a dense plasma that retained the electron band structure of an ordered solid. Titan, the newest addition to the Jupiter facility, is one of only three petawatt-class lasers in the world and currently the only one offering synchronized short- and long-pulse operation. Scientists will use Titan to explore the science of fast ignition for

Jim McNaney (left) and Hector Lorenzana check calibrations on the target chamber of Livermore's Janus laser before a dynamic x-ray diffraction experiment.



inertial confinement fusion (ICF). Titan and other Jupiter facility lasers will also support the development of diagnostics and targets for the National Ignition Facility (NIF) as it comes into full operation.

Progress at the National Ignition Facility

Major progress continues to be made on NIF and preparations for fusion ignition experiments with the 192-beam laser. The NIF project is meeting all of its technical performance, cost, and schedule milestones. Current plans are to complete the construction project in March 2009 and begin the first ignition experiments in fiscal year 2010. NIF's laser beams will compress fusion targets to the conditions required for thermonuclear burn, liberating more energy than is required to initiate fusion reactions. ICF energy is a long-standing program goal within DOE. NIF will offer researchers the capability to study

physical processes at temperatures approaching 100 million degrees and pressures of 10 billion atmospheres, conditions that exist naturally only in the interior of stars and planets and in exploding nuclear weapons.

NIF is vital to the success of the Stockpile Stewardship Program. It is the only facility capable of creating, in the laboratory, the conditions necessary to experimentally study physical processes that occur during the thermonuclear phase of an exploding nuclear weapon. Data from precisely diagnosed experiments will elucidate key weapon performance issues and assist in validating physics models and numerical simulation codes. Over the coming decades, NIF experiments will also help train and rigorously test the capabilities of weapons scientists, upon whom the nation depends to assess the safety, security, and performance of the U.S. stockpile.

In December 2006, the first of four clusters of laser beams completed operational qualification. NIF broke its own record

as the world's most energetic laser and became the first to demonstrate that it can produce over a megajoule of infrared laser energy. The facility has now demonstrated that it ultimately will be capable of achieving 4.2 megajoules in the infrared. By comparison, the Laboratory's previous-generation ICF laser, Nova, typically operated at just over one percent of this energy output.

Laser test shots are being conducted almost on a daily basis. They have demonstrated, for example, NIF's ability to precisely control pulse shape and duration. In addition, the Integrated Computerized Control System has proved its ability to fire an entire shot cycle for a cluster of lasers, from setup to post-shot amplifier cooling, in just over three hours. Meanwhile, equipment continues to be installed. More than 3,200 of NIF's 6,200 line replaceable units (LRUs) have been assembled, tested, and inserted into the beamlines. LRU modules contain instrumentation and optical compo-

NIF's Integrated Computerized Control System handles some 60,000 elements, including safety interlocks, alignment systems, mirrors, lenses, motors, sensors, cameras, amplifiers, capacitors, and diagnostic instruments.



nents and weigh between 500 and 1,000 kilograms each.

NIF Looks toward Ignition

The National Ignition Campaign (NIC), which is being managed for NNSA by the Laboratory, is making significant progress. NIC's objective is to integrate the activities of multiple laboratories to prepare for ignition experiments on NIF in fiscal year 2010 and to transition NIF from project completion to full operations in fiscal year 2012. The goal is to make NIF the international center of high-energy-density science for research in strategic security, energy security, and basic science of matter at extreme conditions. Plans are for a broad-based community to be using the facility 24 hours a day by 2012 for experimental science that cannot be done anywhere else.

In support of NIC, four Integrated Experiments Teams were formed this year in the areas of laser performance,

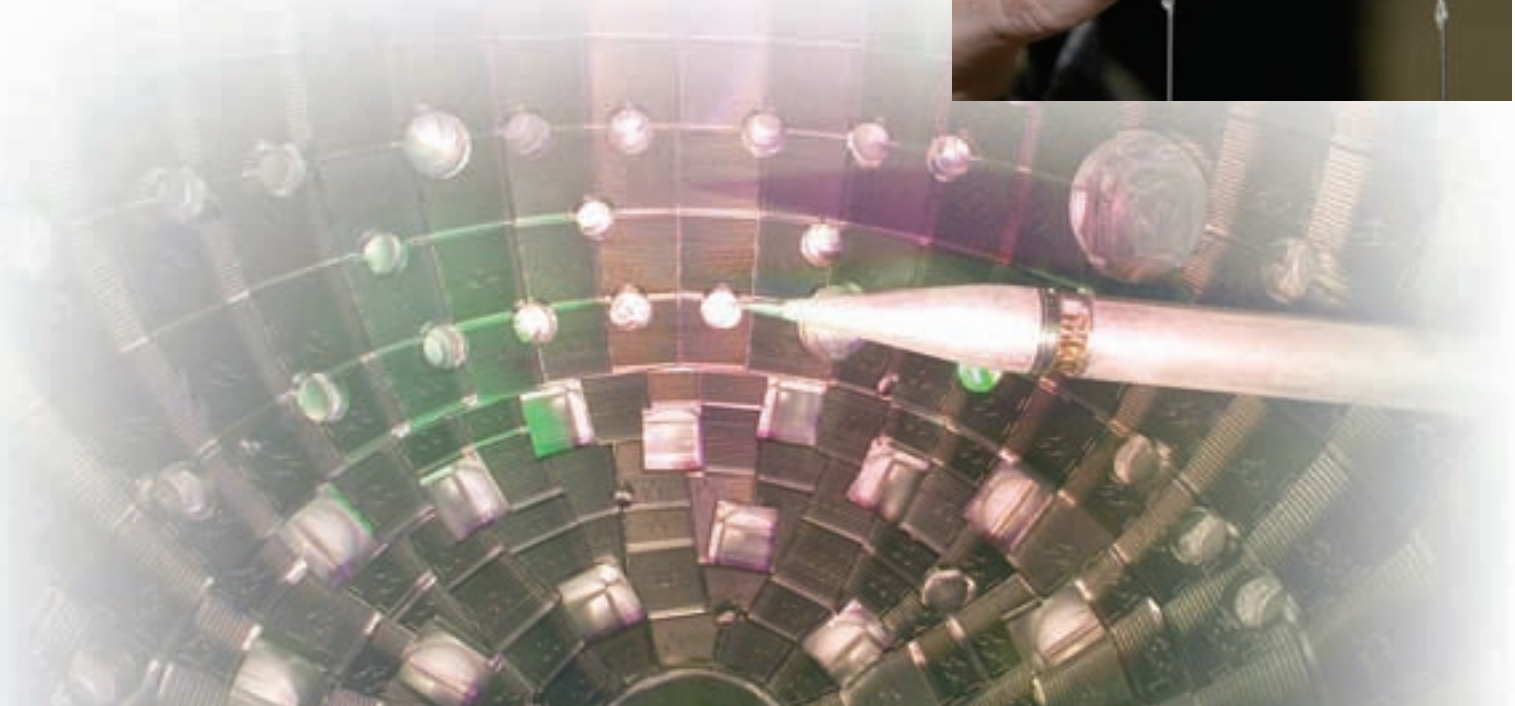
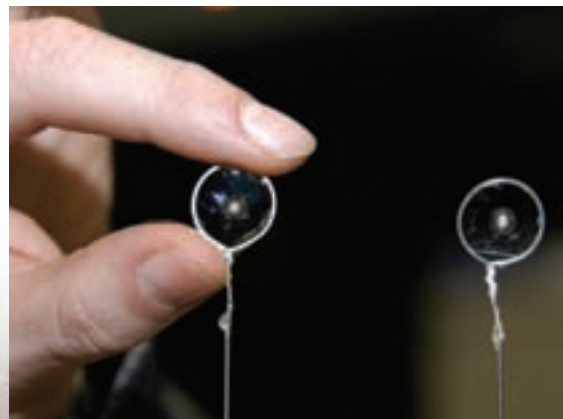
hohlraum performance, capsule performance, and ignition performance. Each team is developing requirements for "tuning campaigns" aimed at reducing risk and optimizing system parameters for the ignition campaign.

The ignition-target point design continues to become more robust. Improvements are based on the combination of simulation modeling efforts and experiments at the Omega laser, Sandia's Z facility, and other facilities worldwide. At Livermore and General Atomics in San Diego, scientists and engineers are progressing in the development of tools and imaging methods for fabricating and characterizing high-precision targets for fusion experiments. Research is moving toward the use of beryllium capsules because they can ignite more efficiently than the plastic shell designs used to date in ICF experiments. In addition, the NIF Experimental Support Technology Program is building and commissioning the experimental systems required for performing user

experiments. These systems include the cryogenic target system, target diagnostics systems, user optics, and personnel and environmental protection systems.

Also in fiscal year 2006, the Laboratory and collaborating institutions developed a NIF High-Energy-Density Physics (HEDP) Plan and an accompanying National Calibration Plan. The goal of the HEDP plan is to identify important experimental weapons-physics data needed to develop and validate predictive capabilities for weapons assessment. The calibration plan defines a process and management structure for calibrating HEDP diagnostics for current and future experiments and a roadmap to deliver the enabling capabilities using facilities across the DOE complex.

When NIF begins fusion experiments, beryllium targets (right) will be filled with a fuel of tritium and deuterium. The target positioner (below) will place a target precisely in the center of the 10-meter-diameter target chamber.



W56 Dismantlement and Support of Production Activities

NNSA announced in June that the final W56 nuclear warhead was dismantled safely and securely at the Pantex Plant as part of the nation's effort to significantly reduce the size of its nuclear stockpile. The W56, an intercontinental ballistic missile warhead that saw service until the early 1990s, was designed at Livermore. As part of its cradle-to-grave responsibilities for the weapons it designs, the Laboratory provided support to Pantex for developing the safety-authorization-basis documents that set requirements for production, surveillance, and dismantlement work activities.

It is the Laboratory's mission to support the production plants to ensure that work is conducted safely and efficiently. Cooperative efforts also aim at improving efficiencies and responsiveness. Where necessary, scientists and engineers pursue research and development to resolve critical issues that impede progress in weapons operations at the production

plants. As an example, Livermore responded to safety concerns about electrostatic discharge at Pantex by developing a new protocol based on a rigorous model and supporting experiments to understand the effect. Conservative procedures were then devised to safely perform necessary nuclear explosive operations.



The dismantlement of all W56 weapons, which were designed by the Laboratory, was completed by workers at the Pantex Plant.



Plutonium Futures

The Laboratory, in collaboration with Los Alamos National Laboratory, hosted "Plutonium Futures: The Science 2006" in July in Pacific Grove, California. This conference provided an international forum for presentation and discussion of current research on physical and chemical properties and environmental interactions of plutonium and other actinide elements. Nearly 400 researchers from more than 28 countries attended. Paper topics were diverse, including transformations due to temperature, pressure, and other causes; actinide compounds storage; reprocessing of spent materials; and remediation of contaminated sites.



Plenary sessions of the Plutonium Futures conference were held in historic Merrill Hall at the Asilomar Conference Center in Pacific Grove.